TITLE: Command and Control System of Unmanned Surface Drones for Sea Mine Disposal

Command and Control System of Unmanned Surface Drones for Sea Mine Disposal

The Automation of Minesweeping Operations
by means of the
Command and Control System (C^2 System) for the
Remote-Controlled Mine Countermeasures System TROIKA

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1. Summary

The following presentation gives an overview about the concept and the capabilities of the new command and control system for remote controlled unmanned surface drones which will be used for disposal of seamines. The presentations shows that a reasonable automation of minesweeping operations with unmanned drones under heterogeneous operating conditions is possible and will improve the sweeping performance significantly.

2. Mission of the Mine Counter Measure (MCM) System TROIKA

- *What is the purpose and the basic configuration of the minesweeping system?*

The TROIKA minesweeping system is used by the German Navy to dispose sea mines (picture 1).

The TROIKA system consists of a manned guidance control platform (GCP) from which of up to three unmanned boats (drones) can be remotely controlled in manual mode. These drones generate magnetic and acoustic signatures which initiate sea mines at a safe distance from the guidance control platform and thus clear the sea area of mines. The drones are designed to survive the mine detonations and remain operable.

The task of TROIKA comprises the transit of the force (guidance control platform and drones) to and from the sea area and the very minesweeping operations themselves in the operating area.

3. The Need for Automation of Today's MCM System TROIKA

- *Why is it necessary to automate minesweeping by the TROIKA system?*

During minesweeping the drones must operate directly in the minefield to initiate the mines. Due to the resulting hazard they must be unmanned during such operations.

The drones are controlled and monitored remotely from the guidance control platform which is located outside the minefield.

At present, remote control is performed manually, i.e. the control commands for the drone are entered by the operator on the guidance control platform, from where they are transmitted to the drone by radio and executed. The drone position is determined by the guidance control platform radar. The operation is not automated.

Such manual remote control has the following disadvantages (pictures 2 and 3):

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- **High manpower requirements**

A control operator is permanently required for each drone because each drone is controlled manually. In addition, one person is required for monitoring the entire operation and the sea area.

- **High stress load for the operators**

The control operators on the guidance control platform can observe and assess the surface situation (drone position and movements, other traffic) only by means of the radar image. This requires enormous concentration and is very monotonous and is thus an extremely stressy job for the operators.

- **Prolonged stress load for the operators**

The sweeping areas are very large; they must be run over by the drones repeatedly and the drones are very slow. Therefore, a minesweeping operation and thus the stress for the operator is very lengthy (up to several days).

- **Varying sweeping performance and success**

The sweeping performance and success depend on how exactly and completely the given sweeping tracks can be covered by the drones. With manual control this is dependent on the operator's attention, current capability and level of training and therefore strongly varies.
The limited observation means (only radar image) make the correct reaction by the operator difficult and reduce the sweeping performance.

- **No permanently evaluation of sweeping progress and no documentation**

The sweeping progress is not permanently documented and evaluated.

All this shows that manual remote control of the drones has considerable disadvantages.

4. Requirements for the Command and Control Capability of the Future Mine Countermeasures System TROIKA

- *What are the requirements for a future minesweeping system with respect to operational command and control?*

The TROIKA minesweeping system has proven to be an efficient means of sea mine disposal in practice, which is underlined by its successful employment in the Arabian Gulf. Germany is currently upgrading its mine countermeasures capabilities. One of the measures taken is to improve the drone control, in order to eliminate the disadvantages of remote control described above and to increase the efficiency of sea mine disposal.
The command and control capability of the new TROIKA system will have to meet the following requirements (picture 4):

1. The operator workload and stress will have to be greatly reduced.
2. The sweeping performance and success will have to be improved.
3. The command and control system shall not affect the planning and conduct of operations.
4. Manual control of one or several drones must always be possible.
5. Changes to the planning and conduct of the operation must always be possible, even during the operation.
6. Nautical safety shall be improved.
7. The current MCM situation and the sweeping success/situation shall be updated and documented permanently.
8. Data exchange (MCM situation, planning data) with other MCM units must be possible.

The operational conditions in times of crisis and peace shall be taken into consideration. Economic solutions shall be realized.

An analysis of the requirements shows that all requirements can only be met with different types of solutions (picture 5). Requirements for a reduced operator workload and stress along with an increased sweeping performance call for an automated high-precision drone control and navigation. On the other hand, manual control without any automation of the drone movement must be possible at any time. And finally, drone control must be flexible enough to permit all the different phases of the operation to be conducted without limitations. If one takes a look at the individual phases of a minesweeping operation, it becomes obvious that for some phases drone control is clearly defined and can thus be automated, while other phases require a situation-oriented definition and can only be semi-automated.

In order to meet all these requirements to the optimum extent, a command and control means will have to permit operating the drones at

various levels of automation, from fully automatic mode to manual mode.

5. Modes of Operation and Levels of Automation

- *How can the requirements for an improved command and control capability by automation be realized and what will such automation have to look like?*

In order to realize the various requirements, different modes of operation with different levels of automation were defined for drone control (picture 6).

The drones are always controlled in one of the two control modes:
(A) Drone unmanned in remote control
(B) Drone manned in local control

<u>(A) Drone Unmanned in Remote Control</u>
In this control mode the drones are unmanned and remotely controlled from the guidance control platform. This can be done in the following modes of operation:
(A1) fully automatic control
(A2) semi-automatic control
(A3) manual control

The individual modes of operation can be freely selected and changed. At the same time, different modes of operation can be performed by several drones.

<u>(A1) Remote Control - Fully Automatic</u>
In this mode a drone or a drone formation is controlled fully automatically. As a prerequisite for using this mode, the entire operation must be completely defined beforehand and the drones must be in a defined status (position and equipment status).
When using this mode, one or several drones can always be switched to another mode of operation.

The mode "Remote Control - Fully Automatic" can be used in two conditions:
(A1-1) Remote Control - Fully Automatic Transit
In this condition the drones automatically follow a reference vessel (the guidance control platform or a drone). It is possible to select whether they follow the track of the reference vessel at a defined distance or whether they synchronously perform the course and speed changes of the reference vessel.
This condition is used when the drones have to be deployed over long distances.

(A1-2) Remote Control - Fully Automatic Minesweeping
In this condition the drones move in a sweeping area and follow a defined sequence which determines:
- the position, number and geometry of the minesweeping tracks to be covered
- the sequence of drone runs
- the type of turns at the end of the track
- the frequency of the track runs
- the drone status during the track runs (type of signature generation, speed, distances)

This condition is used to sweep a sea area.

<u>(A2) Remote Control - Semi-Automatic</u>
In this mode the drones are controlled semi-automatically. The system completely controls the compliance with certain inputs (e.g. course, track, speed...). These must be entered manually, they cannot be defined in advance and they are carried out immediately. This mode can be selected in any drone position and situation.

This mode can be used in three conditions:
(A2-1) Remote Control - Supported Mode - Course Following
Selected course and speed of the drone are controlled automatically.

(A2-2) Remote Control - Supported Mode - Track Following
The drone is automatically kept on a defined track with a defined speed.

(A2-3) Remote Control - Supported Mode - Waiting Circle
The drone is automatically kept on a defined circle with a defined speed. Thus, the drones can be "parked" in a way at a fixed position.

<u>(A3) Remote Control - Manual</u>
In this mode the drone is not controlled by the C^2 system. The operator enters the control commands manually on the guidance control platform and the C^2 system transmits these commands to the drone. This mode corresponds to the capabilities of today's remote control system of the TROIKA.

<u>(B) Drone Unmanned in Local Control</u>
In this control mode the drones are manned and controlled by the C^2 system on the drone. The following modes of operation can be selected:

(B1) semi-automatic control
(B2) manual control

These modes are structured analogously to those of the remote control mode. The only difference is that the control commands are not entered on the guidance control platform, but directly on the drone.

6. Employment of the Different Levels of Automation During Minesweeping

- *How can the different modes of operation and levels of automation be employed?*

The different drone control modes can be used flexibly without any limitations if the individual prerequisites are fulfilled. The employment of the different modes of operation and hence the different levels of automation shall be explained for a typical minesweeping operation (picture 7).

A minesweeping operation basically consists of the following phases:

- preparation of the operation
- transit
- minesweeping
- completion of the operation

Transit and minesweeping can be performed repeatedly.

6.1 Preparation of the Operation

In addition to the usual readying for operation of the vessels, a radio link must be established between the guidance control platform and the drones, in order be able to monitor the drone status automatically from the guidance control platform.

Then, relevant operational parameters and plans must be defined, e.g. how a sea area shall be swept.

If the minesweeping phase is to be performed in fully automatic mode, a plan for the operation must be prepared in advance. This planning can be very extensive since very many parameters must be defined. In order to reduce this effort, the C^2 system offers support tools like automatic generation of track geometries, predefined sweep plans etc. The input of a plan for the operation is also possible via data exchange with different data carrier types. This allows a preparation of these plans on other vessels or on landbase station.

6.2 Transit

Transit is the deployment of the minesweeping force to or its return from the operating area (picture 8). During transit, the force usually covers large distances which takes a relatively long time. Therefore, fully automatic drone control, i.e. the drones automatically follow the manually controlled guidance control platform, appears reasonable.

This type of transit is possible with the "Automatic Transit" mode of operation. Since at the beginning of the transit the drones can be in any status (positions, equipment settings), while an automatic transit requires defined initial settings, this transfer to the defined initial status should reasonably be performed semi-automatically or manually. A fully automatic solution would be technically feasible, but not advisable for economic reasons due to the required efforts. In addition, the benefits would be limited because this transfer is performed only for a short time and not very often.

6.3 Minesweeping

During the minesweeping operation itself the drones shall repeatedly run over tracks in a sweeping area in certain modes (picture 9). Normally, this takes quite some time and requires high-precision navigation. Therefore, this process should be fully automated. The prerequisite for fully automatic drone control is that the drones are in defined positions. As during transit, the drones must be transferred from their random positions to the defined starting positions. For a cost-effective realisation of this automatic mode, this is done semi-automatically or by manual control.

6.4 Avoidance of collisions

During the entire operation, incidents (equipment failures, collision hazards etc.) may occur. Theoretically, an automatic reaction would be technically feasible in many cases; however, due to the unlimited variety of possible failures and in order not to relieve the operator of his responsibility, the automatic execution of a reaction (e.g. automatic course

change without confirmation by the operator) was waived.

In order to increase the nautical safety, the C^2 system performs automatic sea surveillance. Collision hazards for the drones or the guidance control platform with moving surface targets are automatically recognized, evasive maneuvers (e.g. course change, speed change) are recommended, and - if confirmed or adjusted by the operator - performed automatically. The drone in question is then switched to the semi-automatic condition "supported mode - course following".

7. System Description

- *How does the automation effect the system design of the C^2 system?*

To realise high-level, flexible and safety automation of drone control the C^2-System has the following main features (picture 10):

The guidance control platform is equipped with two operating consoles with two screens each, which permit comprehensive information display. One console controls and monitors all drones (max. 4), the other console controls, plans and evaluates the overall operation. A flexible and adaptable human machnine interface (HMI) guarantees easy handling of the C^2 system in each opertional situation.

The drones are fitted with an input device with a display to permit manned control from the drone.

One essential component is a reliable data link between the drone and the guidance control platform. This reliable data link is very important since the drones participate in sea traffic in unmanned mode and must therefore be controllable at any time. Reliability is ensured by several measures, e.g. time division multiple access (TDMA), error correction and diversity operatoin.

8. Realization and Lessons Learned

The command and control system for the control of surface drones has been under development since 1996 in cooperation with the Netherlands (picture 11). Development will be completed in mid-1999 and initial experience can be obtained under real operating conditions. From the year 2000, the new system will enter into service in Germany with the HL 352 class boats (upgrade project HL 343). The same system will also be installed on the Alkmaar class boats of the Royal Netherlands Navy and the use is planned for the German new mine hunting equipment (MJ 2000) which used remotely controlled drones to tow modern sonars.

Simulations with the system and with operators have shown that the operator stress can be significantly reduced with such an automated system.

9. Conclusion

With the new command and control system for the mine countermeasures system TROIKA the German Navy takes its first step towards automated minesweeping.

The design of this system is an example of how automation can be utilized for real operating conditions with heterogeneous and unpredictable situations.

The new C^2 system has the following advantages:

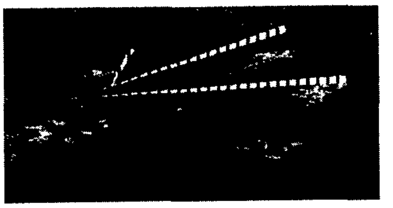
- The automation of drone control reduces the operating effort and the operator stress in such a way that with a manpower reduction from 4 to 2 operators the number of controllable drones can be increased from 3 to 4.
- High-precision navigation in connection with automatic operation analysis and documentation improve the sweeping performance and success.
- Automatic sea surveillance increases nautical safety.
- The use of different levels of automation provides for a flexible, situation-oriented employment and permits an economic realization of the system.

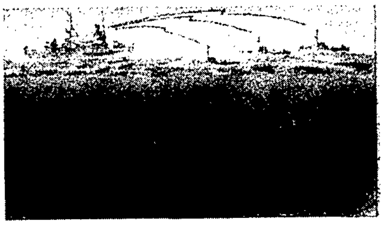
This design of the new C^2 system offers a maximum degree of automation, flexibility and cost-effectiveness for an effective minesweeping.

C²-System TROIKA

Current TROIKA

- Mission of TROIKA:
  - *Disposal of sea mines without endangering of personal*
- TROIKA unit covers:
  - *one manned Guidance Control Platform (GCP)*
  - *three unmanned <u>manual</u> remotely controlled drones*
- Principle of TROIKA:
  - *Unmanned drones generate magnetic and acoustic signatures which initiate mines*





Picture 1

C²-System TROIKA

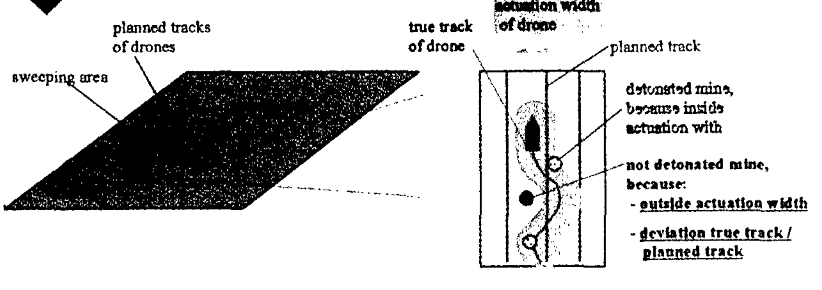
Disadvantages of manual control (I)

- **High manpower requirements**
  - each drones requires one operator and one supervisor
- **High stress load for the operator**
  - observation drones only by radar image
- **Prolonged stress load for the operator**
  - large sweeping areas and large transits / slow drones
- **Varying sweeping performance and success**
  - sweeping performance depends on operator´s attention, current capabilities and level of training
- **No permanently evaluation and documentation**

Picture 2

C²-System TROIKA

Disadvantages of manual control (II)



- Observation errors (radar image !)
- Insufficent manual reaction of operator

➡ Deviations between planned and true track of drones

➡
- Insufficent sweeping success
- Reduced sweeping performance

Picture 3

C²-System TROIKA — Requirements on a new Command and Control System

- Reduction of operator workload
- Improvement of sweeping performance / success
- No restriction by planning / execution of operations
- Possiblility of manual control at any time
- Possiblitity to change operation planning at any time
- Improvement of nautical safety
- Permanently evaluation and documentation of sweeping situation / success
- Data exchange with other units / landbase

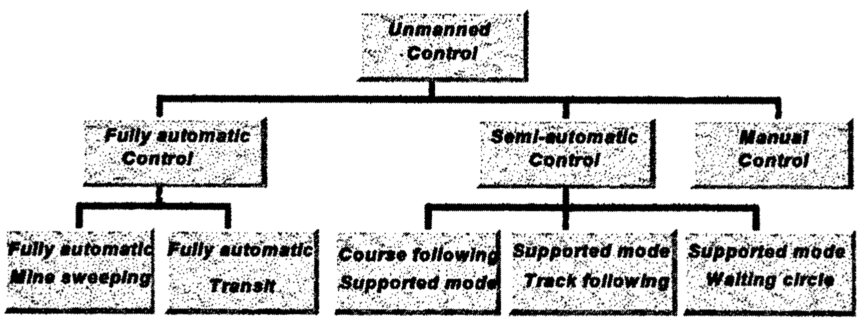
Picture 4

C²-System TROIKA — Solutions

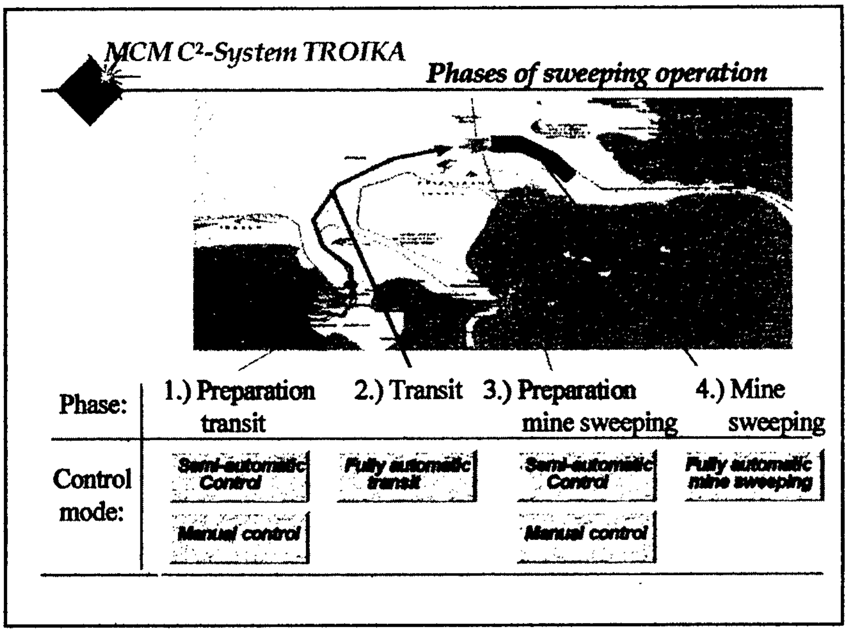
Requirements	Solutions
• Reduction operator workload • Improvement sweeping performance • Permanently evaluation and documentation of	• Fully automation of complete minesweeping operation • Effective and user-friendly operation system
No restriction by planning/execution • Possiblility of manual control at any time • Possiblitity to change operation planning/execution	• Flexibel automation • Different levels of automation for each drone
• Improvement of nautical safety	• Automatic collision detection and support of evasive actions • Reliable data link

Picture 5

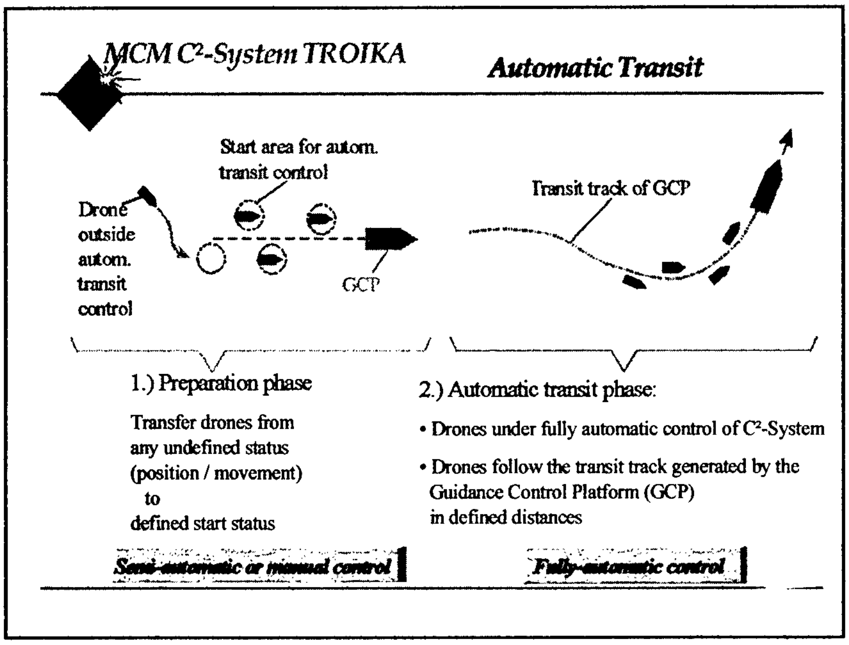
C²-System TROIKA — Different levels of automation



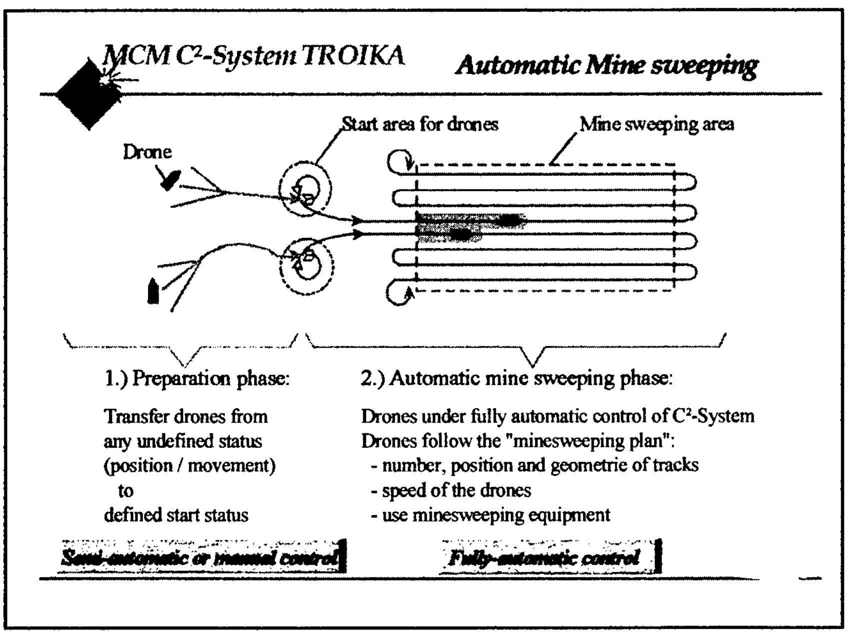
Picture 6



Picture 7



Picture 8



Picture 9

C²-System TROIKA — *Components of new C²-System*

- Guidance Control Platform
  - two identical consols (operator and supervisor) each console two screens
  - interfaces to navigation sensors
  - main computer
  - data link unit

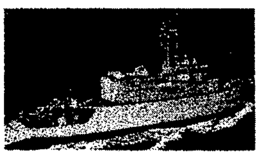
- Drones
  - input device with display (for manual control on drone)
  - interfaces to navigation sensors
  - interfaces to drone control
  - data link unit

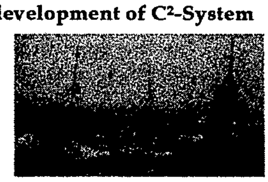
Picture10

C²-System TROIKA — *Use of new C²-System*

Use of new the Command and Control System for remote controlled drones

GE / NL co-operation development of C²-System





- NL upgrade project of Alkmaar class
- In service planned 2002

- GE upgrade project of HL 343
- In service planned 2000

- GE development project of new mine hunting equipment (MJ 2000)
- In service planned 2006

Picture11

C²-System TROIKA — *Conclusion*

- **First step towards automated minesweeping**
- **Automation and high-precision navigation improves sweeping performance / success and reduces operator stress**
- **Flexible automation allows optimal use under any real operating conditions**
- **Automatic sea surveillance increases nautical safety**

Picture12